TEXAS

ENGINEERING TECHNICAL NOTE

Subject : EROSION CONTROL

No. : 210-15-TX2

Reference : UNDERGROUND OUTLETS

Date : JULY 1985

SOIL CONSERVATION SERVICE
U.S. DEPARTMENT OF AGRICULTURE

TEXAS ENGINEERING TECHNICAL NOTE

NO. 210-15-TX2

UNDERGROUND OUTLETS

INTRODUCTION

This technical note provides data, procedures, and examples for preparing designs, construction drawings and specifications for underground outlets (620). It is applicable when underground outlets are used to dispose of excess runoff water from level and graded terraces (600), diversions (362), basin terraces (600) and water and sediment control basin (638).

APPLICATION

Use of underground outlets may result in one or more of the following situations:

1)	Replacement of vegetated waterways	Fig. 1
2)	Reduction of peak discharges	Fig. 2
3)	Improved terrace alignment	Fig. 3
4)	Controlling head cuts	Fig. 4, 5, & 6
5)	Improved water management system	Fig. 7

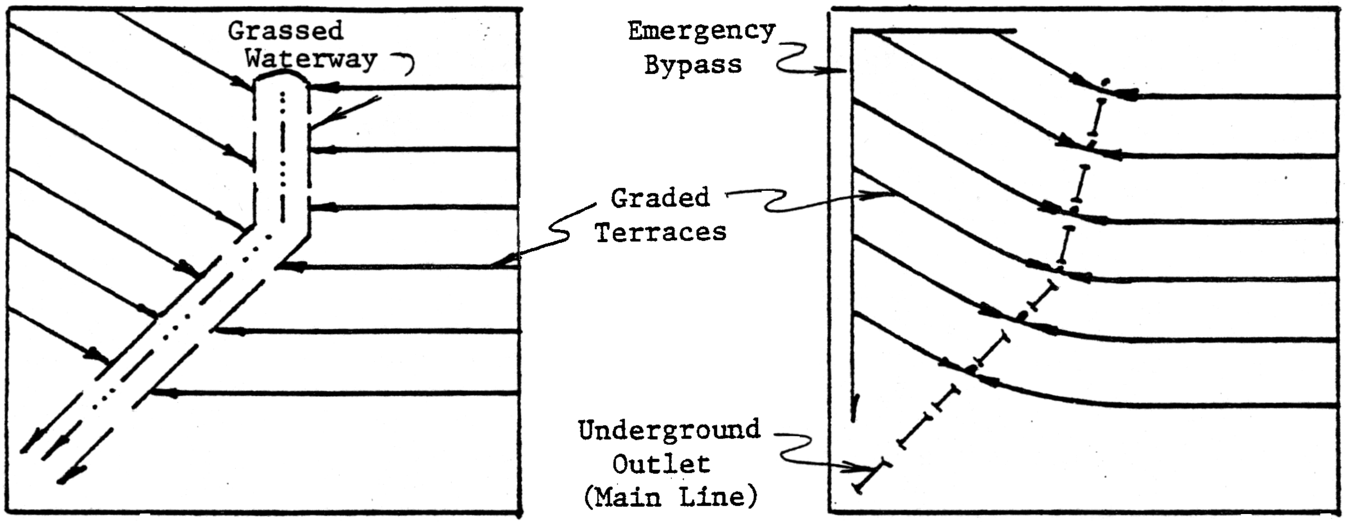


FIGURE 1

Vegetated waterways are often used as outlets for graded and level terrace systems. In areas where vegetation is difficult to establish and/or maintain, underground outlets offer a viable alternative.

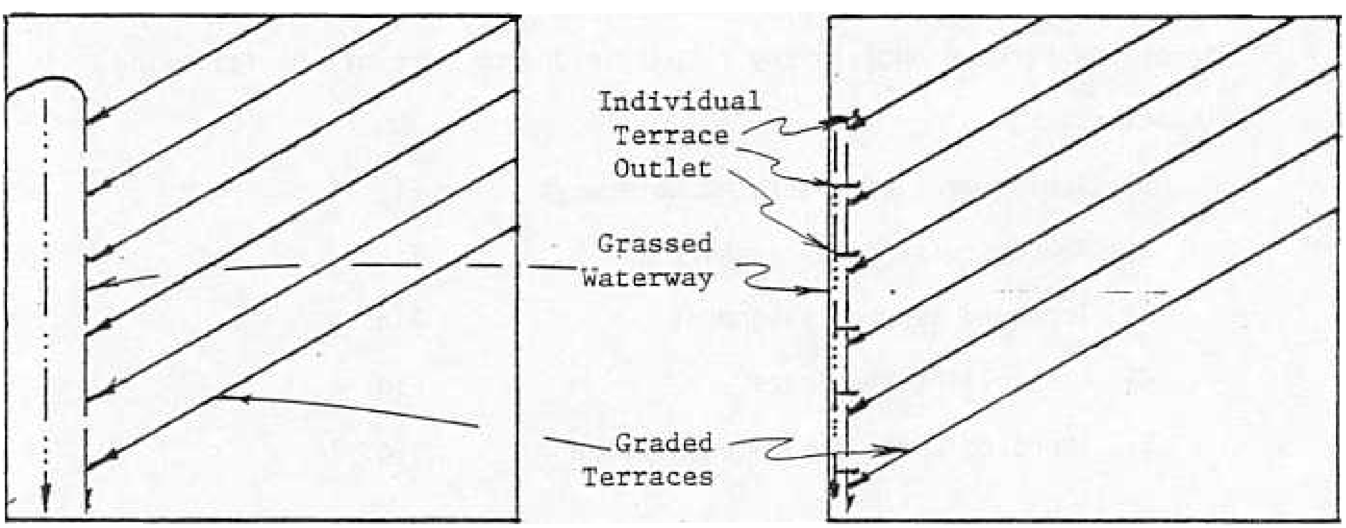


FIGURE 2

Reducing peak discharges may significantly reduce the required size of downstream conservation practices. For example, the use of underground outlets to discharge runoff from a terrace system into a grassed waterway outlet will decrease the required capacity of the waterway.

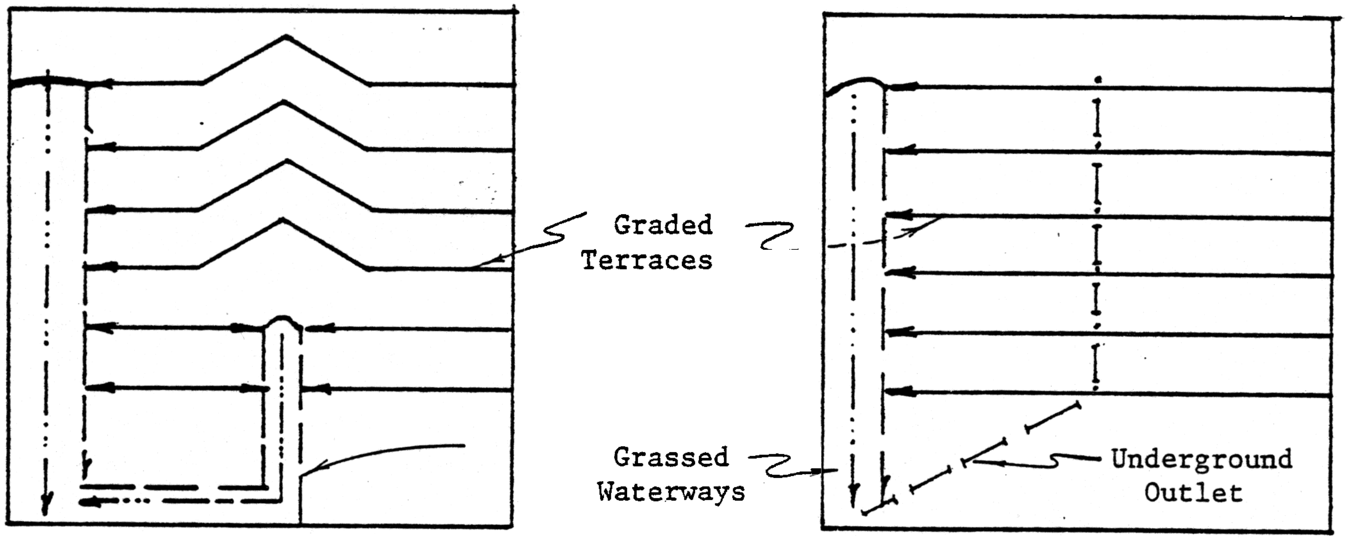


FIGURE 3

Underground outlets may be used to eliminate small waterways or extensive cut and fill areas in parallel terrace systems, and result in the installation of a more farmable terrace system.

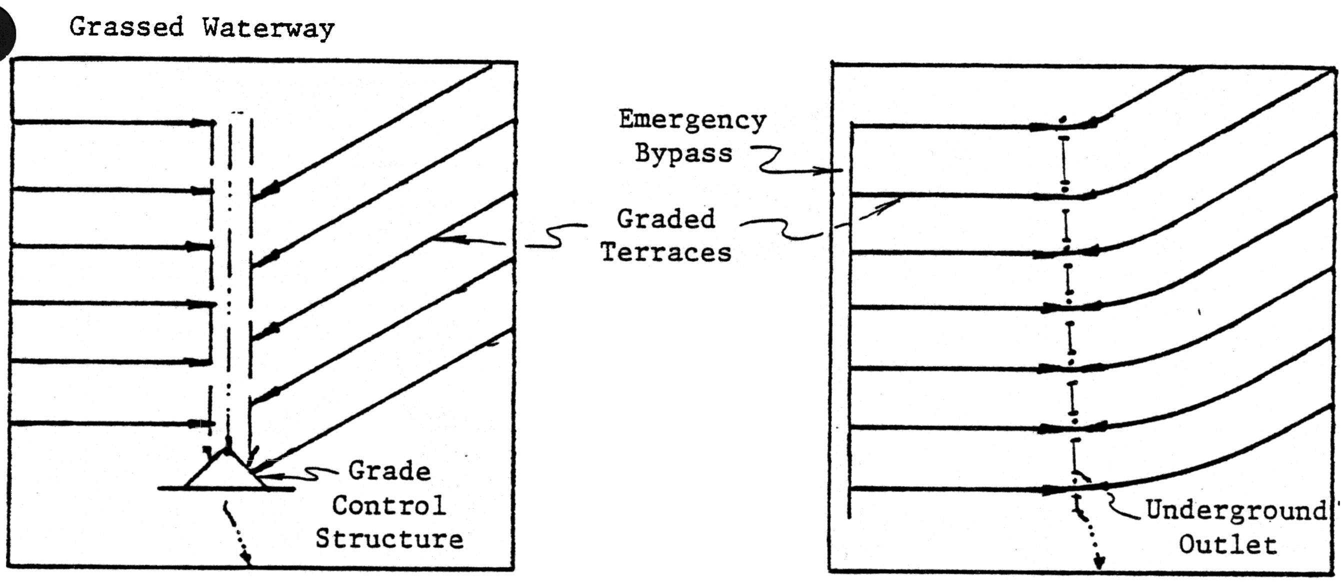
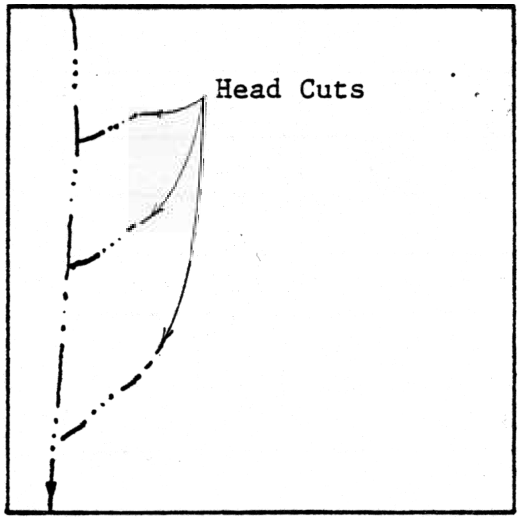


FIGURE 4

A graded terrace system with underground outlets may eliminate the need for a waterway and concrete chute or pipe drop.



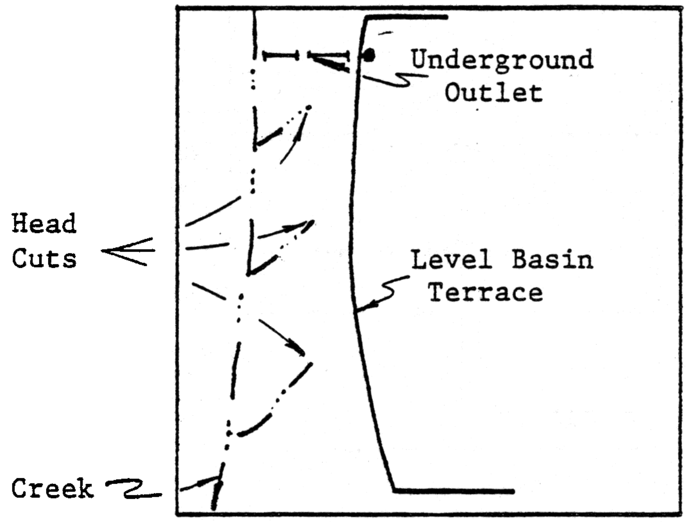
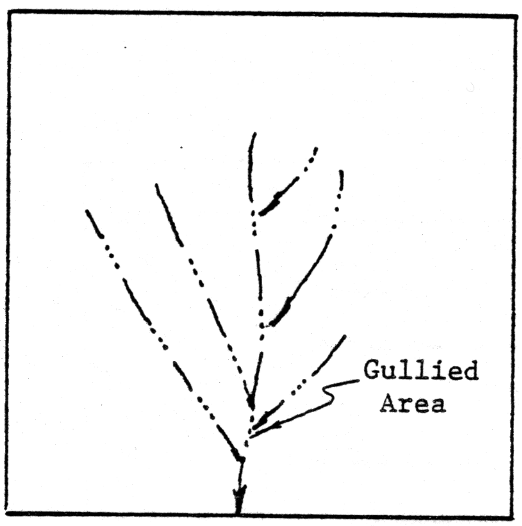


FIGURE 5

A level basin or diversion terrace with an underground outlet may be used to store and discharge runoff water from a flat field into a deep gully or creek.



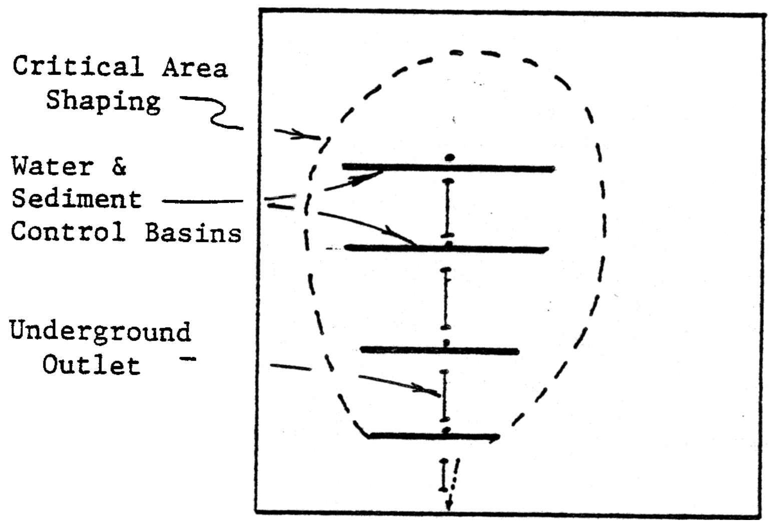


FIGURE 6

Water and Sediment Control Basins with underground outlets can be used to stabilize critical area shaping.

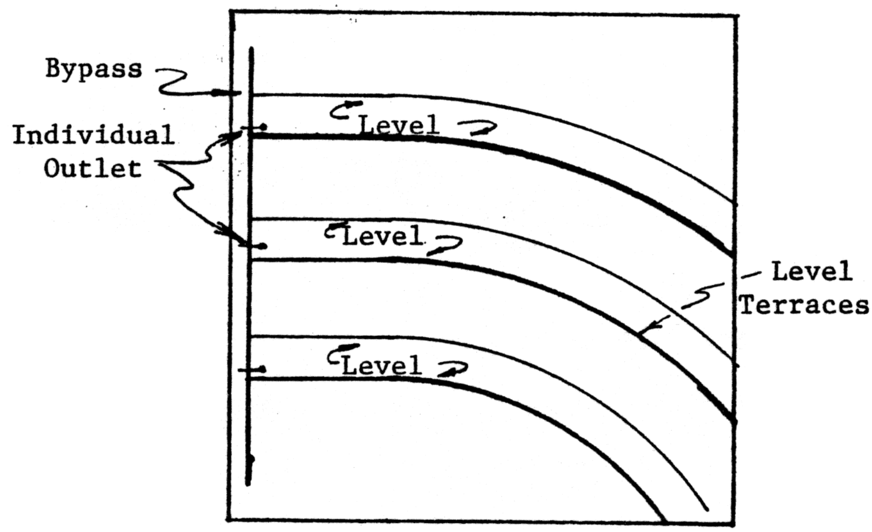


FIGURE 7

In semiarid regions, terraces with underground outlets can be utilized to manage runoff water for water conservation purposes. The underground outlet gives the flexibility to store water in the soil profile, or to allow runoff be removed at a nonerosive velocity.

DESIGN

Underground outlet design criteria is contained in the National Handbook of Conservation Practices (NHCP), Underground outlets (620) along with criteria for practices installed in conjunction with underground outlets. The design procedure wi   be divided into the following categories:

I. Estimating Required Storage

II. Determining Design Heights

III. Hydraulics of the Underground Outlet

IV. Developing Construction Drawings and Specifications

I. Estimating Required Storage

Sufficient storage must be provided to prevent the terrace or structure from overtopping. The volume of required storage will depend upon:

1) Sediment yield
2) Runoff yield
3) Release rate

Sediment Yield

Sediment storage is the volume allotted to sediment deposition during the design life of the structure. The volume of sheet and ril erosion can be estimated by the Unified Soil Loss Equation (USLE). Generally, ephemeral and gully erosion should not occur upstream of structures with underground outlets; however if they do, sediment storage should be allotted for that sediment yield also.

Most underground outlet systems wi be designed in conjunction with other conservation practices that reduce erosion rates to less than allowable. f that is the case, a simple method of estimating sediment storage is to assume 5 tons loss (max. allowable loss) over the watershed draining into the structure. Assuming d = 90lbs/ft³ then:

$$\text{Sediment yield} = \frac{(5\ \text{tons/Ac/Yr})\ (2{,}000\text{lbs/ton})\ 12\ \text{in/ft}\ (\text{Yrs})(\text{Ac})}{90\ \text{lbs/ft}^3\ 43560\ \text{ft}^2/\text{Ac}}$$

Sediment yield (Ac-In.) = .03 (Yrs) (Ac)

Yrs = design life of structure in years

Ac = drainage area in acres

Runoff Yield

Procedures for estimating runoff volumes from small watersheds are contained in Chapter 2 of the Engineering Field Manual and Texas Engineering Technical Note No. 210-18-TX5. The Tech Note also contains a procedure for adjusting Runoff Curve Numbers for Average Runoff Condition. This adjustment can significantly reduce the design runoff volume. Judgment is necessary to determine if a reduced C.N. will be used for the design storm. For example, the designer may choose to use the reduced CN if flow through the bypass area would result in minima damage and the land user historically has performed maintenance on other conservation works and systems presently designed seldom overtop. However, he may choose to ignore the reduced C.N. if flow in excess of the design storm would cause severe damage, or the land user has been somewhat lacking in performing maintenance, or historically the area has had a large problem with terrace overtopping

Release Rate

The required volume of storage is the sum of the sediment and runoff yield. However, the structure may not be required to store the total runoff yield because discharge through the underground outlet may occur during the passage of the design storm. A DAMS2 computer model or procedure contained in Texas Engineering Technical Note TX210-15-TX1 can be used to route the design storm event through the underground outlet. A simpler less accurate method to estimate storage requirement is the use of a discharge coefficient. The total required storage is the runoff times the discharge coefficient plus sediment yield. Discharge coefficients are a function of the removal rate and the runoff from the design storm event. The following coefficients were developed assuming a Type II 24-hour storm with curve numbers ranging from 60 to 80 rainfalls ranging from 4 to 8 inches. They assume a uniform discharge from the underground outlet. The most conservative discharge coefficient for the above mentioned conditions is given.

Hrs. Removal Time	Discharge Coefficient
6	.40
12	.48
18	.54
24	.60
30	.63
36	.66
42	.70
48	.73

Discharge coefficients are a simple relatively accurate method of estimating required storage; however, the designer must recognize the assumptions made during the design process. A constant discharge rate is assumed for the entire design storm. Hydraulic design procedures discussed later assure the design assumption is met. It is necessary that the underground outlet system be properly designed hydraulically if a routing coefficient is used.

II. Determining Design Height

Structures used in conjunction with underground outlets must be high enough to provide the required storage capacity. Storage can be obtained from excavation, or natural storage. In the case of a terrace, excavated storage is obtained by building it from the upper side, while terraces built from the lower side contain only natura storage. The actual storage capacity can be calculated by end area methods. Matching actual storage to required storage is a trial and error solution that can be adapted to a programable calculator. A simpler more direct approach is to account for excavated storage by selecting confining boundary as shown on figure 8 and develop a stage storage curve based on natural storage. The curve can be developed using a grid map (Fig. 8). The surface area defined by the confining boundary and contour lines can be measured with a planimeter, squaring the area into geometrical figures that can be calculated or by counting dots or squares within the confined area or other methods that would give similar accuracy. The accumulative storage is computed and plotted against elevation. The elevation that produces the required storage is the design elevation.

If a grid map is not available, the storage volume for graded terraces can be estimated by the following formula if grade and natural ground slope are constant:

$$\text{Storage} = \frac{.4592(D_o^3 - D_e^3)}{s\ g}$$

Where Storage = Available storage in Ac.-in.

D_o = The design height in ft. at the vertical inlet

D_e = Design El. minus ground elev @ upper end of terrace valve must be zero or greater

s = Slope of natural ground in ft./ft.

g = Terrace grade in ft./100 ft.

If terrace length is adequate to assure D_e = 0 then the D_o may be obtained by:

$$D = [2.1776\ (\text{Required Storage})\ (s)(g)]^{.3333}$$

When the natural ground slope or terrace grade are not constant, the following formula may be used to estimate the storage

$$\text{*Storage} = \sum \left(\frac{D_o^2}{s_o} + \frac{D_1^2}{s_1} + \frac{D_2^2}{s_2} + \frac{D_n^2}{s_n} \right) .01377$$

Where storage = Available storage in Ac.-in.

D_o = Height of terrace 50 ft. upstream of vertica inlet (ft.)

D_n = Difference in ft. beneath ground line of the confining boundary at the design elev. at station n

s_n = Slope of ground norma to terrace at station n in ft./ft.

*Stations must be 100 ft. apart begining at 50 ft. from vertical inlet.

The above formulas assume the natural ground slope extends uniformly above the terrace to design elevation. If structures such as another terrace is located within the design elevation then the formulas are not correct and other procedures should be used to estimate storage

Structures should be built to detain the design storm, but should be able to pass a larger event through an emergency bypass area. The minimum freeboard above the design elevation should be .5 ft.

The terrace end closure should be built similar to the details shown in Fig. 9. The minimum length of (L) (ft) shown in Fig. 9 should be equal to or greater than the runoff volume in Ac. in. i.e. if the volume of runoff is 25 Ac.-in. then the minimum required L is 25 ft.

III. Hydraulics of Underground Outlet

The underground outlet should be designed to remove runoff water from the structure at a rate sufficient to prevent damage to crops. The rate of removal is a function of the available head and the hydraulic sizing of the underground outlet. The average required rate of removal can be calculated as follows:

$$\text{Required Average Discharge} = \frac{\text{Ac. in.}}{\text{Hr.}} \text{ or } \frac{\text{Cu.Ft.}}{\text{Sec.}} = \frac{\text{Volume of Runoff(Ac.in)}}{\text{Removal Time (hrs.)}}$$

The following assumption is made:

Average Discharge = .8 design discharge

Design Discharge = 1.25 Average Discharge

The maximum remova time should be 24 to 48 hours

Design discharge occurs at design elevation. The underground outlet system should be sized to pass the design discharge. The underground outlet system consists of the following components:

1) Vertical Inlet
2) Offset Line
3) Orifice
4) Main Line

The vertical inlet is the portion of the underground outlet system that is exposed. It usually consists of a pipe with holes or slots that allow runoff water to enter the underground outlet.

The height of the vertical inlet should extend to the design elevation. The minimum diameter should be the larger of the following:

1) Two inches larger than orifice
2) The same size as the offset line connected to the vertical inlet
3) Large enough to prevent pipe flow in the riser section. (Exhibit 5)

The holes or slots should be large enough to prevent plugging with trash, but small enough to prohibit trash from entering the underground outlet. The area of the individual opening should range from approx. .75 sq in. to 4 sq in. The total open area of the inlet should be adequate to pass at least 1.5 times the design discharge. Assuming the openings are uniformly spaced, a discharge can be estimated as follows:

$$Q = \int CA\sqrt{2gh}\ dh$$

$$Q = 3.21\ A\ h^{3/2} \Big|_{h=0}^{h=L}$$

Where:

Q = discharge in Cu. Ft. Sec

C = orifice constant of .6

A = area of openings in sq. in.

g = acceleration of gravity 32.2 ft/sec

h = head on the orifice (ranges from 0 to L where L is the length of vertical inlet above ground.

$Q = .02229\ (A)\ L^{3/2}$

$A = Q\ /.0229\ L^{3/2}$

The minimum opening per ft of inlet can be calculated by the following:

$$\text{Min. opening sq in./ft} = \frac{1.5 \text{ X max Discharge (cfs)}}{0.229\ (L\ (\text{ft}))^{3/2}}$$

$$= \frac{65.5 \text{ max discharge}}{L^{3/2}} \text{ or } \frac{65.5 \text{ (max discharge)}}{L\ (\sqrt{L})}$$

Furthermore, the min. number of 1" diameter opening per ft can be calculated:

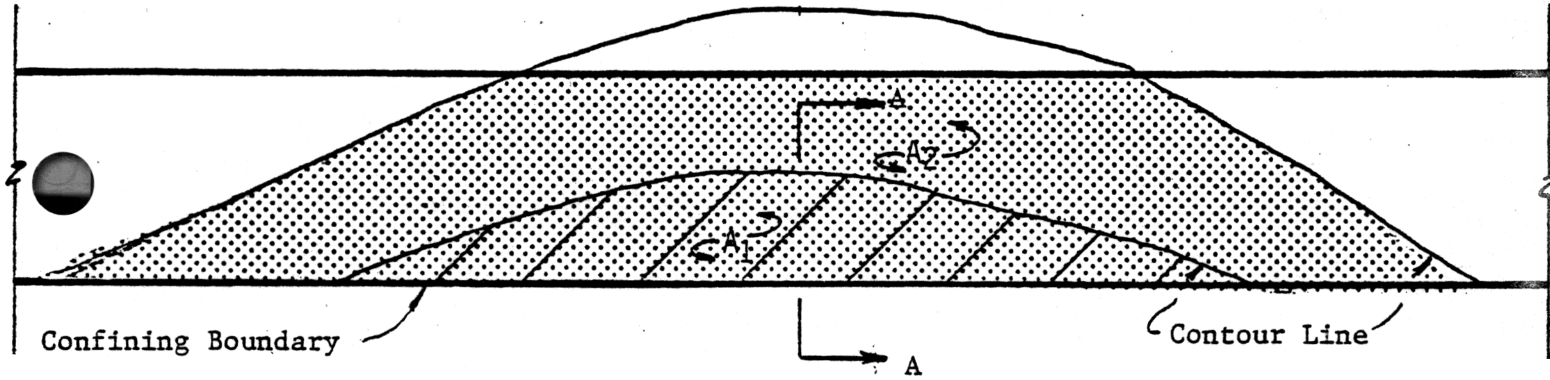
$$\text{Number of 1" diameter openings/ft} = \frac{\text{Min opening sq in./ft}}{\frac{\pi(1.0)^2}{4}}$$

$$= \frac{\text{Min opening sq in./ft}}{.7854}$$

Vertical inlet design (Exhibit 5) is included in this tech note to assist analysis of the minimum open area for vertical inlets.

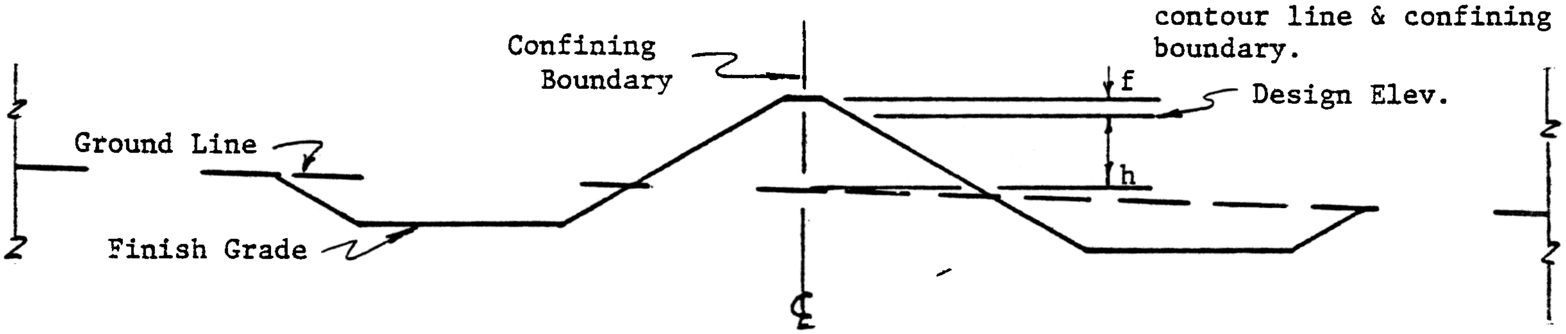
Offset Line

The offset line is the horizontal underground pipe line that connects that vertical inlet to the main line, or an open channel. An offset line will not be required if the vertical inlet discharges directly into the main line. If possible offset lines should be installed as shown in Fig. 9.

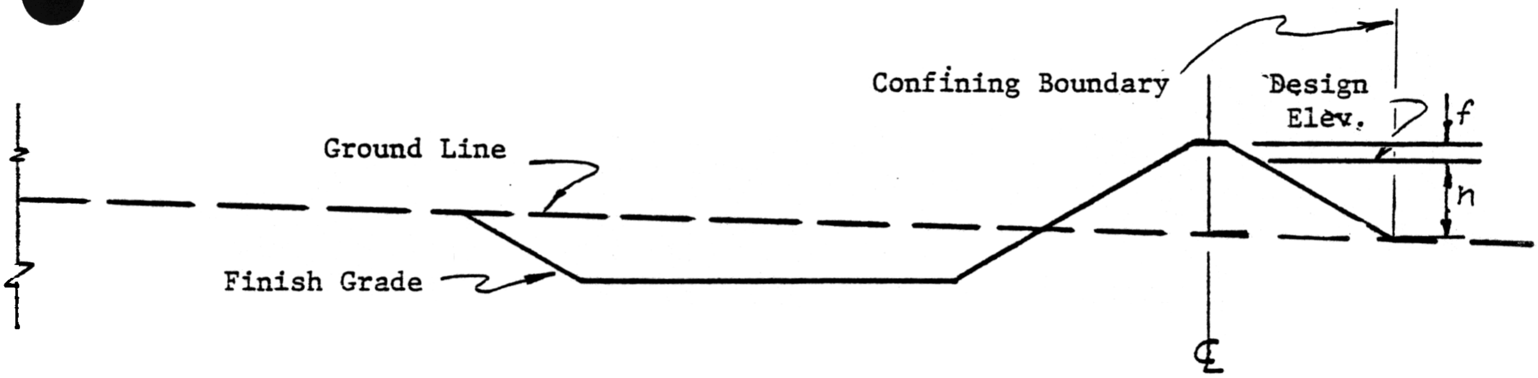


A_1 = Area between the lowest contour line & confining boundary.

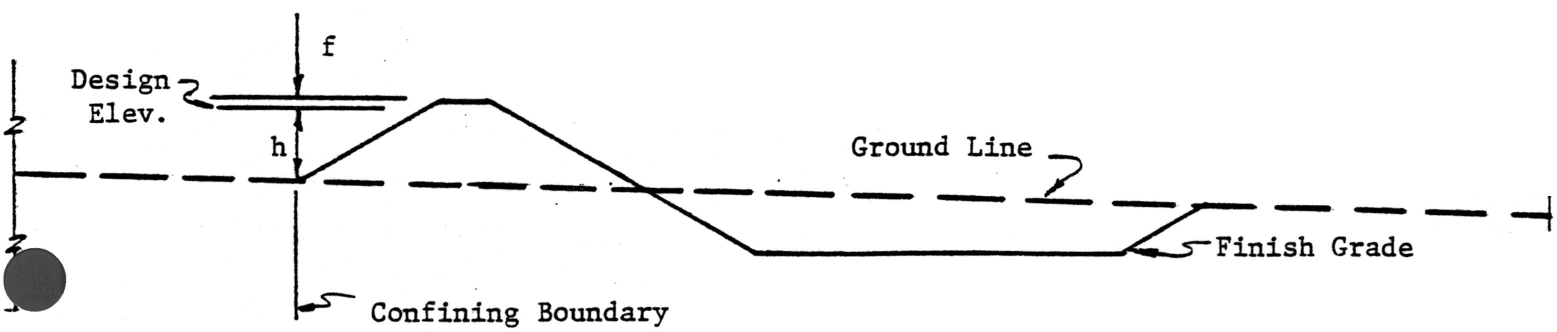
A_2 = Area between the upper contour line & confining boundary.



SECTION A-A
(Terrace built from both sides)



SECTION A-A
(Terrace built from upper side)



h=design height
f=freeboard(min .5')

SECTION A-A
(Terrace built from lower side)

FIGURE 8

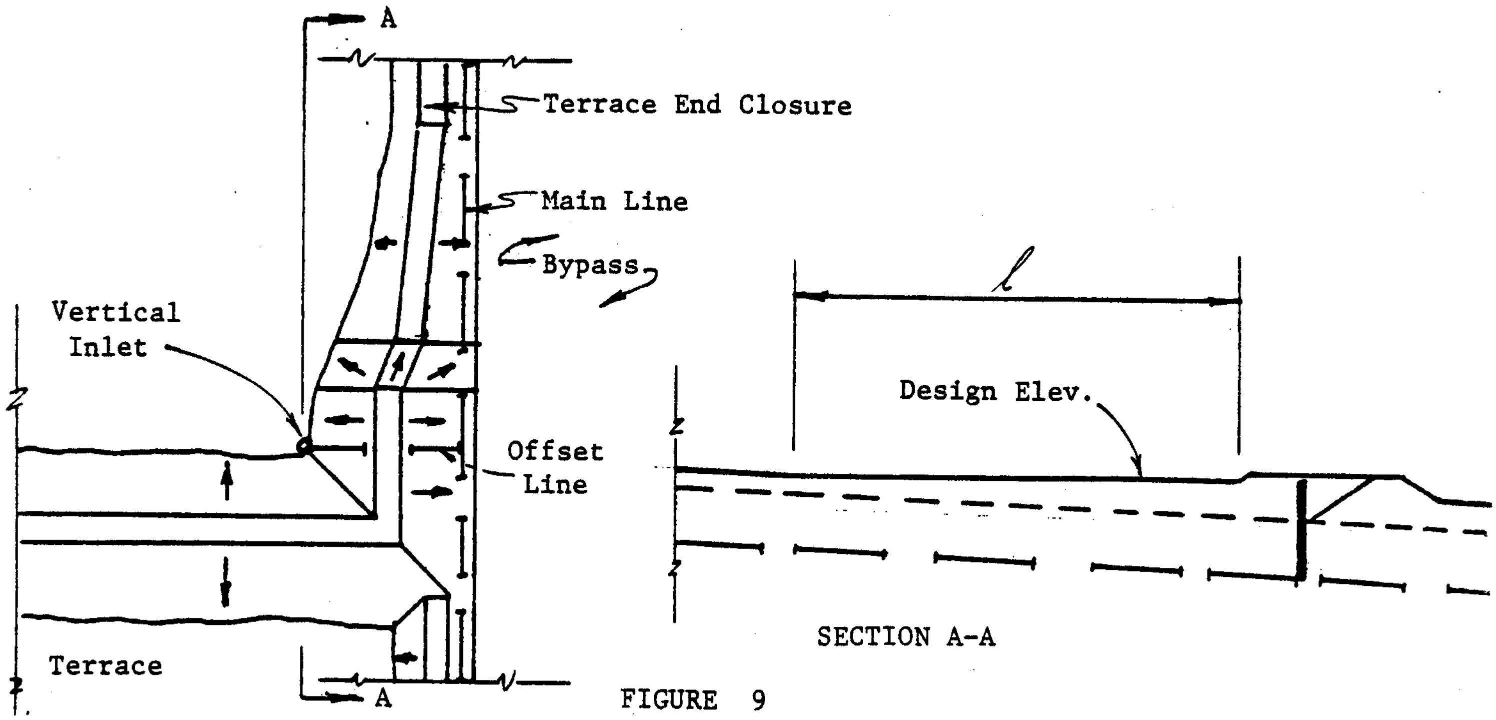


FIGURE 9

The offset line should be sized so that it will pass the design discharge. Full pipe flow may occur. The capacity of the offset line is a function of available head, and its size and roughness. If an orifice is installed, the head (hp) on the offset line should be restricted to 1 ft. (See Fig. 10.)

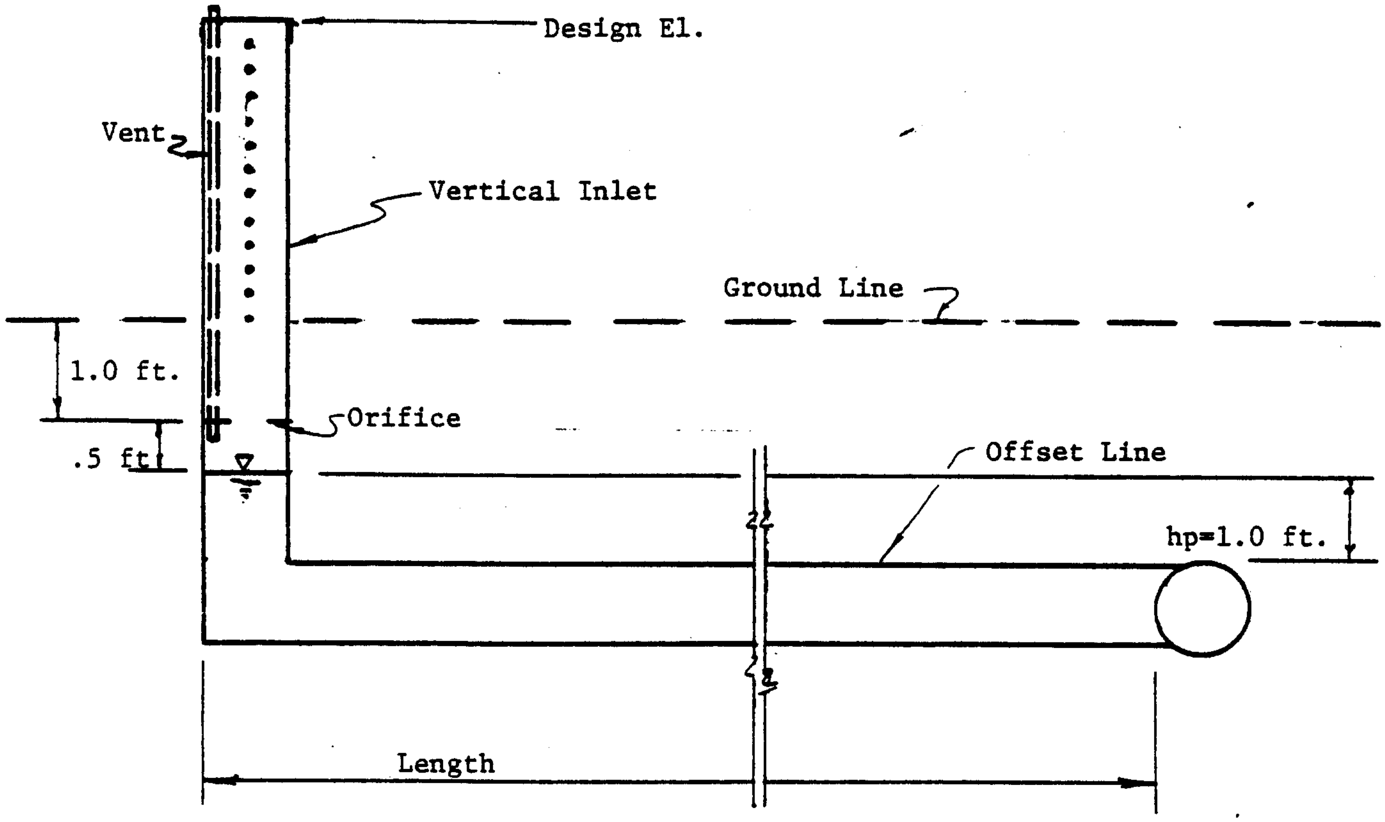


FIGURE 10

If an orifice is not installed, the head on the offset line is the difference between the design elevation and the tailwater elevation at discharge. (Fig. 11).

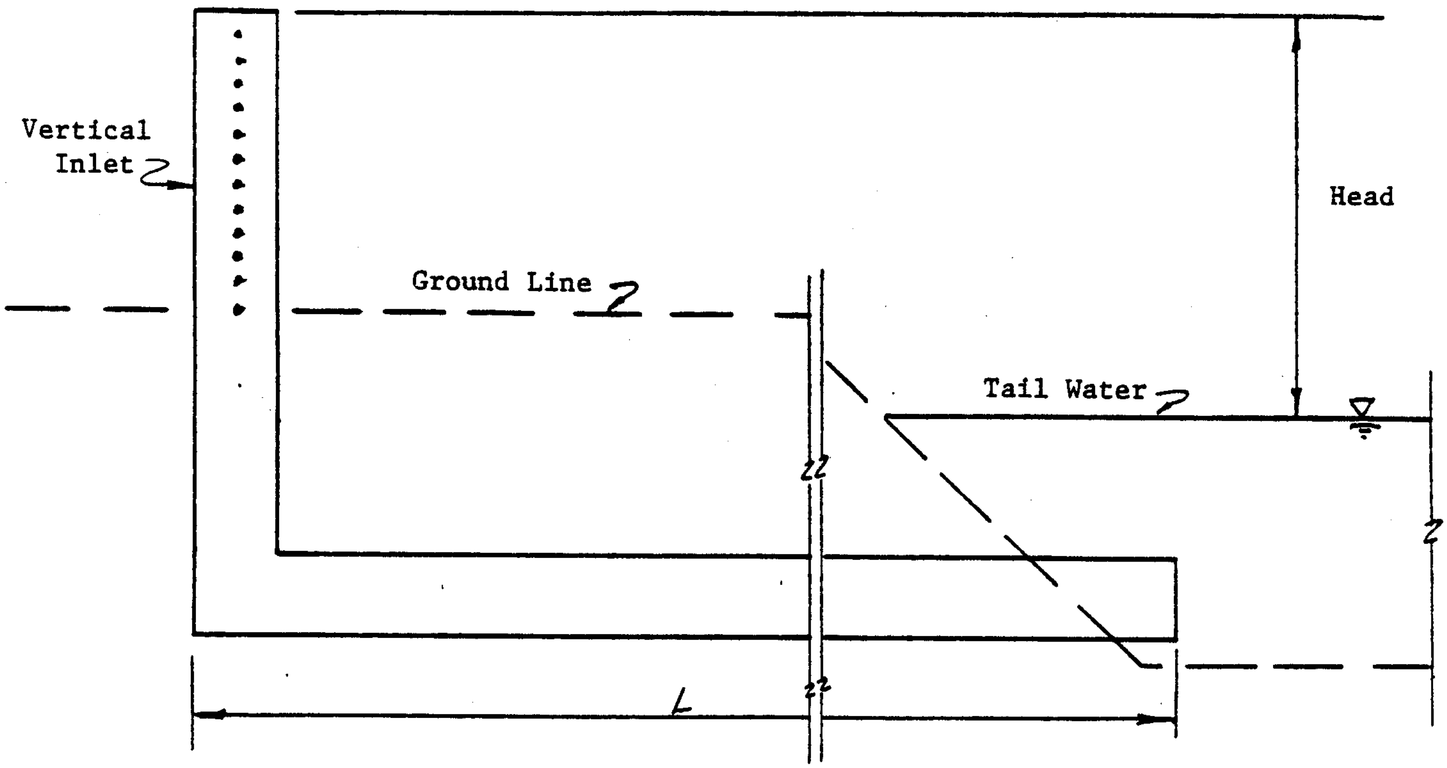


FIGURE 11

The pipe flow formula can be used to estimate flow capacities.

$$Q = A \sqrt{\frac{2\,gh}{1 + k_e + kp\,L}}$$

Q = discharge (cfs)

g = acceleration of gravity 32.2 ft/sec^2

A = Cross section area of pipe ft^2

h = Head on the pipe (ft)

k_e = Entrance loss assumed 1.0

kp = Friction loss factor based on pipe roughness

L = Length of pipeline as shown in Fig. 10 & 11 ft.

Exhibit 6 estimates pipe flow capacities for various sizes, lengths and heads. A Manning's n value of .015 is recommended for corrugated tubing and an "n" value or .011 for smooth plastic pipe.

Orifice

An orifice will usually be required to control the release rate from the structure if it discharges into a main line with other structures. The orifice should be designed to pass the maximum discharge at design elevation. The orifice flow formula can be used to estimate flow capacities

$$Q = CA \quad 2\ gh$$

Where: Q = discharge cfs

C = Orifice coefficient assumed .6

A = Cross section area of orifice

g = gravitational acceleration 32.2 ft/sec^2

h = head above orifice ft (See Fig. 10)

Assuming a round orifice with d = diameter in inches

$$A = \frac{\pi d^2 (\text{in.})}{4\ (144)\ \frac{\text{sq in.}}{\text{g ft}}}$$

$$Q = (.6)\ \frac{\pi d^2}{(4)\ (144)}\ \sqrt{(2)\ (32.2)\ h}$$

$$Q = .02.625\ d^2 \qquad \sqrt{h}$$

or

$$d = \sqrt{\frac{(38.1)\ (\text{Max Discharge cfs})}{\sqrt{h}}}$$

The orifice flow formula assumes that discharge is in the atmosphere. If the orifice becomes submerged (does not discharge into atmosphere) it may not function as a control device, but merely as a minor restriction to flow. To assure the orifice operates as a control it is located 6" above the water surface and is vented to the atmosphere, as shown in Fig. 10.

Main Line

The function of the main line is to deliver runoff from the structure or structures to a stable outlet. The main line should be sized to release the total actua maximum discharge from all inlets. It should be designed to assure head assumptions made in the vertical inlet and offset lines are met. The capacity of the main ine can be estimated from Manning's formula as follows:

$$Q = \frac{A\ 1.486\ r^{2/3}\ s^{1/2}}{n}$$

Q = discharge in cfs

A = Cross section area of pipe in sq ft

n = roughness factor (dimensionless)

r = hydraulic radius (defined as the Area/Wetted Parameter ft)

s = energy head loss

$$r = A/W\ P$$

$$A = \frac{\pi d^2\ (\text{in.})}{4\ (144)\ \text{in.}^2/\text{ft}^2}$$

$$r = \qquad = d/48$$

$$Q = \frac{\pi d^2\ (1.486)}{(4)\ (144)\ n} \left(\frac{d}{48}\right)^{2/3} s^{1/2}$$

$$Q = \frac{.000614}{n}\ d^{8/3}\ s^{1/2}$$

Exhibits 1 and 2 may be used to size the main lines. The available slope and the required discharge can be entered to obtain a minimum main ine size. The required main ine size should be reevaluated to account for accumulative discharges from vertical inlet and changes in slopes. The main line should be vented at locations where slope changes could cause collapse of the pipe due to vacuum or affect design release rates

Construction Drawings and Specifications

After all design functions are complete, a set of construction drawings (Exhibit 7) and specifications (Exhibit 8) should be developed to assure minimum requirements are met. The preparation of construction drawings consists of recording the design and structural requirements graphically in sufficient detail to allow a person unfamiliar with the project to lay out and complete the project as designed. In addition written specifications to clarify how the work will be done, the quality of workmanship, testing methods, required materia quality, method of measurement, etc. should be completed. Any requirement for completion of the job should be detailed in the construction drawings and specifications and meeting those requirements should be the basis for accepting or rejecting the project

Example

Problem: Design and underground outlet for the terrace system shown in Attachment 1.

Solution: Use Standard Form TX-ENG-35 and TX-ENG-35A, Attachment 2 (6 sheets) Attachment 3 (1 sheet).

(1) Drainage Area -- The area that contributes runoff to the system in acres.

(2) Runoff Curve No. -- Engineering Technical Note No. 210-18-TX5, Exhibit 2 and Form TX-ENG-66.

(3) Rainfall -- Rainfall for design storm inches, Exhibit 3 Engineering Technical Note No. 210-18-TX5.

(4) Runoff -- Runoff from design storm, Exhibit 4 Engineering Technical Note No. 210-18-TX5 or Technical Release No. 16.

(5) Volume of Runoff -- Drainage Area Acres x Runoff (inches) = Ac-in

(6) Discharge Coefficient -- Obtained from footnote 1/ on Form TX-ENG-35

(7) Sediment Storage -- Assumes 5 Tons loss from watershed= .03 (in/yr X Design Life (Yrs) X Drainage Area (Acres) =

(8) Total Required Storage -- Volume of storage required to detain the sediment runoff yield minus the outlet discharge for the design storm =(Discharge Coefficient)(Runoff Volume) + Sediment Storage=Ac-in.

STAGE STORAGE -- Information is obtained from topographic map. One foot contour intervals are used to develop a stage storage curve. The elevation of the natural ground at the vertical inlet is the beginning of the curve. Storage at that elevation is assumed to be zero. The area encompassed by first contour ine above terrace and the terrace is measured or calculated. The storage at that contour line is that area in Acres x 1/2 depth in inches between the first contour and the natural ground at the vertical inlet. Next the area confined by the second contour line and the terrace is measured or calculated. The areas previously calculated are averaged and multiplied by 12 inches to obtain the storage for that interval in acre-inches. That volume is added to the previous volume to obtain accumulated volume. The procedure is continued until the total accumulated volume exceeds the total storage required. A curve of depth use storage is plotted. The curve is used to determine the design elevation for the total required storage

(9) Design Elevation -- the elevation at which the required storage capacity is met. It is obtained from the stage storage curve

(9a) Design Depth at Inlet -- The design elevation minus the natural ground elevation at the inlet.

(10) Settled Construction Height -- The Design Depth at Inlet plus Freeboard for typed detention structure installed. A minimum of .5 ft freeboard should be used

(11) Remova time is the selected time for dewatering the structure

12) Design Discharge -- The Runoff Volume for the design storm divided by the removal time in hours times 1.25. The answer is expressed in Acre-Inch/Hr or cfs

Orifice Design

13) Design Orifice Head -- is the design depth plus 1.0 ft.

14) Q - is the design discharge from (12)

(15) Orifice Size -- obtained from Exhibit 3. An orifice size is selected that will pass the design discharge at the design orifice head.

(16) Actual Discharge -- the rate of water removal through the selected orifice at the design depth. It will be equal to or greater than the design discharge.

Offset Line

w/orifice -- design procedure used when an orifice is installed in the vertical inlet.

17) Length - the length of the offset line measured from the main line or outlet to the vertical inlet. "n" is the Manning's "n" value for the type pipe used. (.011 is suggested for smooth pipe and .015 for corrugated tubing.)

(18) Hp = 1.0

(19) Q = The actual discharge from (16)

(20) Diameter - From exhibit 6. Find diameter of offset line which exceeds actual Q (16) with Hp = 1.0 and length and "n" value shown in (17).

W/o orifice - design procedure used when an orifice is not installed in the vertical inlet.

(21) Hp is the design elevation (9) minus the water surface elevation at the outlet. The elevation of the crown of the offset line may be used.

(22) Q des = the design discharge from (12)

(23) Dia. = from exhibit 6 find the dia. of offset line which exceeds the design discharge from (16) with an Hp shown on (21) with "n" value and length shown in (17).

(24) Actual Q = The actual discharge of the offset line selected in the previous step. It must equal or exceed the Design Discharge (12).

(25) Minimum Area Opening sq in/ft -- the opening required in the vertical inlet per ft. It is obtained from exhibit 4 using Actual Discharge from (16) or (24) and the design height (9a).

(29) Minimum number of 1" holes per ft -- can be calculated by dividing the minimum Area Openings sq-in/ft (24) divided by .7854.

(30) The minimum diameter of the verticial inlet is the larger of either one. The offset line diameter (20) or (21) the diameter of the orifice + 2" or the diameter obtained from exhibit 5 using Q from (16) or (24) and design depth shown on (9).

Main Line Design

No. -- The terrace or structure no.

Station -- The survey station of main line structure No. given above.
Normally the main line stationing should start at 0+00 of the outlet and increase numerically upstream

Length -- The length of the line between the two stations in question

Design Elevation -- The elevation obtained in block 9 of form

Ground Elevation -- The elevation of the natural groundline at the station.

This elevation should be plotted on the form

Top of the Main Line Elevation -- The elevation of the crown of the mainline at the station. This is normally 2.5 ft below the normal groundline; however, it may be manipulated to effect the H.G.L. Slope.

Δ Elevation H.G.L. -- The difference is elevation of the hydraulic grade line between the two stations in question. If orifices are used in the design Δ Elevation H.G.L. is the difference between the top of main line. If an orifice is not used

Δ Elevation H.G.L. would be the difference in elevation of water surfaces for the two stations in question

Δ Elevation/Length -- the Δ Elevation of H.G.L. obtained above divided by the length of mainline between the two stations in question.

H.G.L. slope - is the slope in ft/100 obtained from OE//Length

Q design - the design Q from (12

Q actual - the actual Q from (16) or (24)

Acc Q actual - the sumation of actual Q from each inlet.

Dia. Main - the required diameter of the main line to pass the Acc Q actual at H.G.L. slope obtained from exhibit 1 or 2.